Estimating Soil Moisture in a Boreal Old Jack Pine Forest

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Abstract - Polarimetric L- and P-band AIRSAR data, corresponding model simulations, and classification algorithms have shown that in a boreal old jack pine (OJP) stand, the principal scattering mechanism responsible for radar backscatter is the double-bounce mechanism between the tree trunks and the ground [1]. The data to be used here were taken during six flights from April to September 1994" as part of the BOREAS project. The dielectric constants, or equivalently moisture contents, of the trunks and soil, can change rapidly during this period. To estimate these dynamic unknowns, parametric models of observed radar backscatter for the double-bounce mechanism are developed by using a series of simulations of a numerical forest scattering model. The resulting simulated data are used to derive polynomial fits of backscattering cross section as a function of the ground and trunk dielectric constants. Empirical and field data are used to relate the real and imaginary parts of the dielectric constants, and hence formulate the parametric model in terms of two unknowns only. Three data channels, P-HH, P-VV, and L-HH are used to solve for the two unknowns. A nonlinear optimization procedure is used to estimate the dielectric constants, and hence, in particular, soil moisture. Point ground measurements are used to verify the results of the estimation algorithm.

INTRODUCTION AND RATIONALE

The boreal ecosystem atmosphere research (BOREAS) project is a multidisciplinary effort to study the interactions between the boreal forest biome and the atmosphere to determine their role in global change. BOREAS is focused on two principle study areaa in central Canada, one near the Prince Albert National Park in Saskatchewan, or the Southern study area (SSA), and the other near Thompson, Manitoba, or the Northern study area (NSA). During the time period of April 1994 to September 1994, several intensive and focused campaigns were carried out, in which several remote sensing instruments made measurements. In particular, the NASA/JPL airborne synthetic aperture radar (AIRSAR) collected polarimetric C-, L-, and P-band data during several flights in this time period. In this work, we concentrate on the data acquired over an old jack pine (OJP) stand in the SSA. The SSA contains several conifer forest types such as young and old jack pines and black spruce. There are also deciduous species such as aspen, as well aa stands consist ing of mixtures of these species.

A major goal of performing remote measurements, such as radar measurements using the AIRSAR, was to attempt to retrieve forest parameters that play significant roles in the functioning of the ecosystem. An important such parameter is soil moisture under the forest canopy. Soil moisture content has implications in the rate of transpiration, on water stress, and in the growth rate of forests. The latter is especially important in studying the factors limiting the growth of older trees.

In this work, an estimation algorithm was developed to obtain the soil moisture of an old jack pine stand for six different dates in the Spring and Summer of 1994. The site was chosen due to its specific structure, which as described below, enabled a simplified modeling of the scattering process. As shown in [1] and further substantiated using the classification algorithm of [2], at P- and L-bands (P-HH, P-VV, and L-HH), the mechanism almost entirely responsible for the backscattered signal over the OJP site is double-bounce scattering between trunks and ground. For L-VV, the branch-ground interactions also become significant. Therefore, a parametric scattering model was derived in terms of the dielectric constant of the trunks and the dielectric constant of soil. This model was then used in a nonlinear estimation algorithm to estimate the two dielectric values from P-HH, P-VV, and L-HH AIRSAR data. A few point comparisons of the results with ground-truth measurements were performed and good agreement observed. With the availability of further ground-truth data, more thorough validation will be performed.

SITE DESCRIPTION

The old jack pine stand is one of the four main flux tower sites of BOREAS southern study area. It is characterized by tall trunks resembling cylinders, a sparse crown layer, and a "smooth" floor covered by dry lichen. Some stand parameters are: tree density $= 0.3/m^2$, trunk height $= 15.1 \pm 3.0$m, diameter at breast height $= 13.0 \pm 4.9$cm. These were measured directly during the summer of 1994.

AIRSAR DATA

AIRSAR data from several dates in the Spring and Summer of 1994 were used to estimate the soil moisture and assess its changes at the OJP site. The specific dates were April 17, 20, and 26, June 11, July 28, and September 20. The data channels used were P-HH, P-VV, and L-HH. Although the L-VV backscattered signal was also predominantly characterized as double-bounce, it included the scattering between the branch layer and ground, and therefore was not used in the estimation. Images and representative values of the above data will be shown at the presentation.

ESTIMATION

A two-step procedure [3] was used to estimate soil moisture, or equivalently, dielectric constant, from SAR data:

1. Derive a parametric scattering model from a numerical forest scattering model [4], with the dielectric constants of soil and tree trunks as the independent parameters. Empirical relations were used to relate the real and imaginary parts of soil and trunk permittivity, so that only one of them, in this case the real part, was taken as the parameter to be estimated. The other quantities which define the forest, and in particular, the double-bounce scattering process, are tree height and diameter distributions, trunk density, and soil roughness characteristics. Within the timeframe of this study, which spans about 5 months, this group of parameters can be assumed not to have changed, and therefore fixed in the derivation of the parametric models. The fixed values are those measured in the field and reported in Table 1. Model simulations are shown in Fig. l(a)-(c). The parametric model is derived by fitting two-dimensional polynomials of higher-order to the curves shown. In this case, due to the smoothness and slow variations of the backscattered signals as shown, it was found that polynomials of third order are more than sufficient to describe the parametric model.

2. Use a nonlinear estimation algorithm to find the best set of parameters (soil and trunk dielectric constants) that describes the SAR data given the parametric model. The algorithm used here was an iterative one using the conjugate gradient method. The data covariances were included in the analysis, as well as prescribed parameter covariances to represent a regularization procedure.

RESULTS AND SUMMARY

The algorithm described above was applied to the six AIRSAR data sets, and soil dielectric (moisture) maps produced over the OJ P site. Three of these are shown in Fig. 2, where we observe the decreasing trend in soil moisture from a thawing day in April to late September. Point ground-truth measurements available using a TDR (available for the July data) were used for verification. More comprehensive results, a covariance analysis using synthetic data, and ground-truth comparisons will be shown at the presentation.

There are currently no means for completely validating the results of this algorithm, since a map of measured soil moisture over the entire OJP stand is not available. However, if sufficiently varied number of point validations are made, then the results can be considered validated for all the points within the range of the validated values. It should also be mentioned that the OJP forest was considered due to its structural simplicity. In general, the scat tering process in a forest consists of several mixed mechanisms. A complete solution is left for future versions of this algorithm.

ACKNOWLEDGMENT

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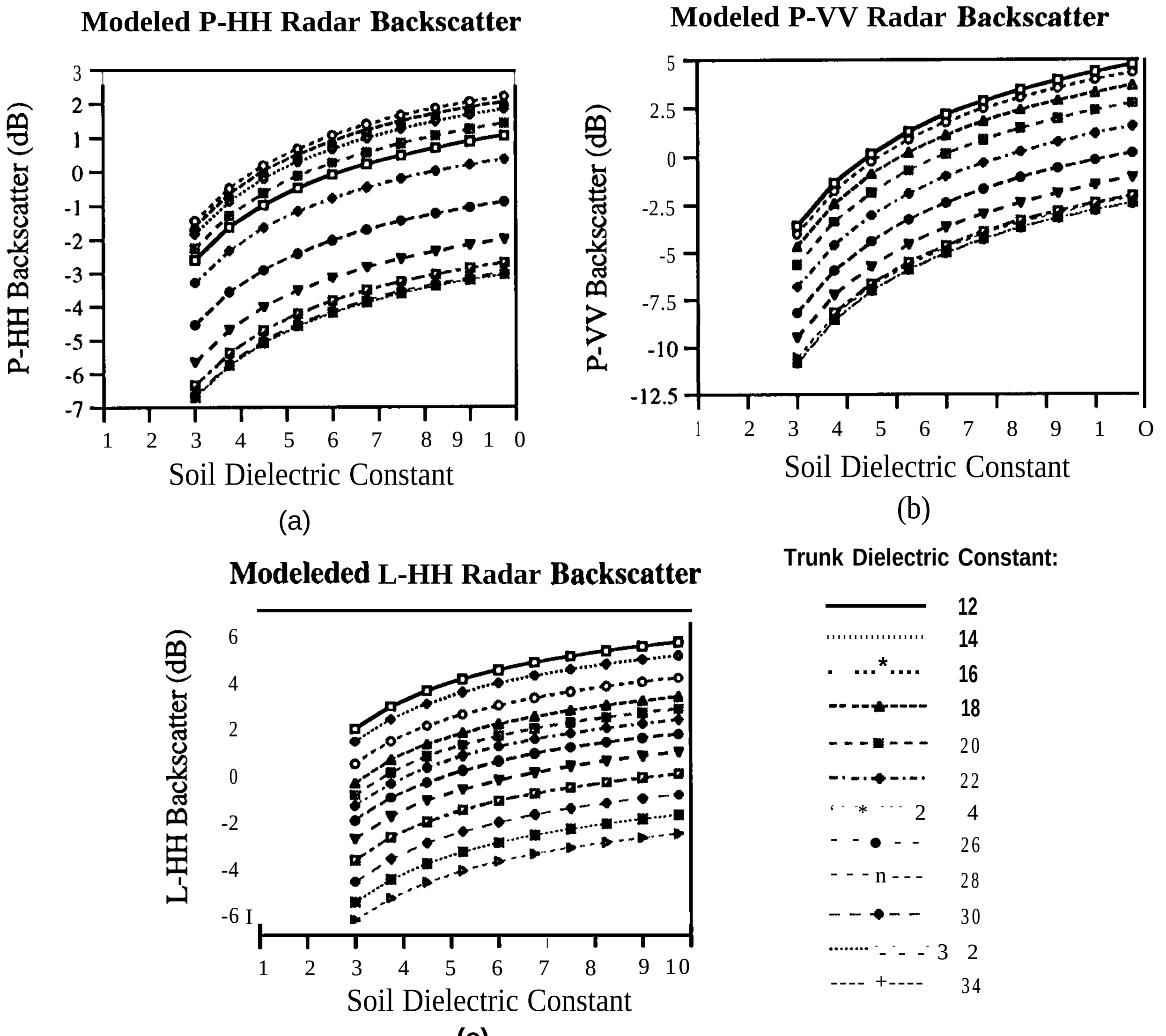
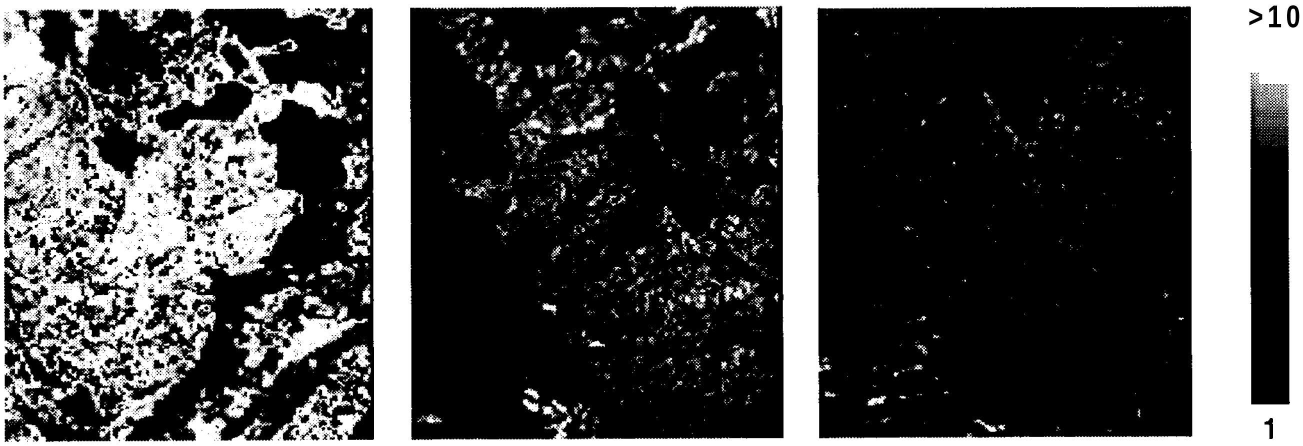


Figure 1. Radar backscatter curves from numerical forest scattering model for the BOREAS SSA OJP site.



(a) (b) (c)

Figure 2. Estimated soil dielectric constant (soil moisture) for the BOREAS SSA OJP site for (a) April **17,** 1994, **(b) July 28, 1994, and (c) September 20, 1994, using** AIRSAR data.